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How Carbon Nanotubes be used in Mechanical Applications

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Carbon Nano Tubes (CNTs) have excellent electrical and mechanical properties. Their Young's modulus is about 1 TPa, and the tensile strength reaches about 11-63 GPa [1-3]. These extraordinary properties make them very attractive for advanced mechanical applications.

At microscopic scale, CNTs have promised bright future for Nano Electro Mechanical Systems (NEMS) through the successful demonstrations on high frequency oscillators [4], rotational actuators [5], nanometer tweezers [6] and nanometer cargoes [7]. These NEMS devices possess unique motion capabilities that are useful for a range of sensing and detection applications. The ultraminiature sensors could provide spatial resolution at the atomic scale and vibrate at frequencies in the gigahertz range, making them possible to measure the forces between individual biomolecules [8], forces arising from magnetic resonance of single spin [9], and perturbations that arise from mass fluctuations involving single atoms and molecules [10]. In addition, high young's modulus and low specific weight of single-walled CNTs qualify them as ultimate mechanical resonators for studying mechanical motion in quantum regime. Strong coupling between single-electron tunneling and nanomechanical motion in CNTs has been observed [11,12].

At macro scale level, great progresses have been made in CNT actuations by coupling CNT's excellent mechanical properties and electrical properties. Large strain and high stress actuators have been studied based upon CNT electrostatic actuation [13], CNT electrochemical actuation [14], and CNT-polymer actuation [15]. Although practical actuators are still under developing, the success of direct conversion of electrical energy into mechanical energy from these actuations offers the opportunities for a number of high-technology applications, including humanoid robots, artificial and damaged hearts, artificial limbs, medical prosthetic devices, bird- or insect-like air vehicles, etc [16].

Ultimately, it is better to prepare CNTs as structural materials, in order to fully explore their superior mechanical properties. But the dimensions of CNTs, a few nanometers in diameter and up to millimeter in length [17], have confronted us with great challenge in conventional reinforcement approach, i.e., dispersing random CNTs into polymer matrix to fabricate reinforced composite materials. This approach has faced at least two major problems [18,19]: poor dispersion and poor load transfer. Because of van der Waals attractive forces, CNTs, especially for long CNTs that are essential for effective load transfer, tend to aggregate into bundles, making uniform dispersion into a polymer matrix extremely difficult. The non-reactive nature of the CNT's outer wall yields relatively weak bonding at CNT-polymer interface; this in turn gives poor load transfer from matrix to CNTs. As a result, all currently reported experimental data are significantly below theoretical predictions. Even in the future when these two limiting factors are eliminated to some extent, low CNT volume fraction in composites will still limit the performance of the final products. Luckily, recent progresses [20-24] in neat CNT fibers demonstrate the possibility to retain CNT's excellent properties at larger scale and more practicable level. The CNT fibers have been reported to have tensile strength of 1~3 GPa, Young's modulus of 100~260 GPa, toughness of 100~900 J/g, and density of 0.2 g/cm3. These progresses motivate further study of lightweight and high strength composites for possible structural applications.

Nevertheless, CNT's future still strongly depends on our capabilities on two extremes: controllability of CNT structure at atomic level, and the capability of retaining the properties of individual CNTs at assembly level. Particularly for CNT assemblies, which are still much poor in performance compared with individual CNTs, future research need to focus on the understanding of the failure mechanism of CNT assemblies, aiming at finding key limiting factors and thus providing reliable and high performance CNT assemblies for practical applications.

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